

Design of an educational platform based on augmented reality for the special education of children with dyscalculia

Jhair Baltodano-Payahua¹, Sebastian Ramos-Cosi¹, Alicia Alva-Mantari¹, Gustavo Villar-Mayuntupa², Enrique Lee Huamani¹, Meyluz Paico-Campos¹, Laberiano Andrade-Arenas¹

¹Facultad de Ciencias e Ingeniería, Universidad de Ciencias y Humanidades, Lima, Peru

²Facultad de Humanidades y Ciencias Sociales, Universidad de Ciencias y Humanidades, Lima, Peru

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ABSTRACT

Dyscalculia is a learning disorder that affects between 3% and 8% of the world's population and is characterized by difficulty in acquiring basic mathematical concepts, mainly in children. In view of this, several technological tools have been explored that can help improve the education of these children, with augmented reality (AR) being a promising alternative. The objective of this research is to design an AR-based platform to support the special education of children with dyscalculia. An agile methodology, Scrum, was used for the development, which allowed for an interactive approach to the design of the prototypes. Consequently, these were evaluated and validated by six experts in the field. The result was an acceptance rate of 81.2%, demonstrating the viability of the prototype. It is concluded that the prototype using AR is an effective tool to support children with dyscalculia aged 8 to 10, as it allows for an interactive and beneficial learning experience to nurture their knowledge.

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Corresponding Author:

Laberiano Andrade-Arenas

Facultad de Ciencias e Ingeniería, Universidad de Ciencias y Humanidades

Lima-Peru

Email: landrade@uch.edu.pe

1. INTRODUCTION

Education in Peru presents several gaps, among them the lack of attention to special educational needs. It is mentioned that in Peru only 52% of children with special needs attend an educational institution, which is alarming, considering that education is an important pillar in a developing country [1]. In this regard, it should be noted that the incorporation of innovative technologies in education is becoming increasingly common, with augmented reality (AR) and, to a lesser extent, virtual reality (VR) being some of the tools with the greatest potential to strengthen teaching and learning processes, especially for students with special educational needs. These technologies not only make learning attractive and interactive, but also offer significant opportunities to optimize the educational experience and promote inclusion [2]. In Peru, the use of inclusive educational technologies is still in its infancy, with limited projects aimed at addressing specific learning disabilities. This situation reinforces the need to develop digital teaching tools that respond to the cognitive and emotional characteristics of children with specific disabilities, such as dyscalculia.

A persistent cognitive condition having a neurological foundation, developmental dyscalculia primarily impacts the comprehension and manipulation of numerical amounts [3]. It stems from a deficiency in the natural representation of numerosity, which prevents the acquisition of fundamental mathematical abilities [4]. It is described as a developmental condition that shows up in math learning even in the presence of sufficient intelligence and a supportive educational environment, emphasizing its enduring character,

potential genetic component, and potential emotional and behavioral ramifications [5]. When combined, these insights help us comprehend dyscalculia as a persistent and distinct mathematical learning disability, whose early detection and instructional strategy are critical to reducing its impact on children's academic achievement and day-to-day functioning.

On the other hand, in [6] it is mentioned that dyscalculia is a disorder that affects between 2.27% and 6.4% of schoolchildren. Despite its importance, dyscalculia is a learning disability [7] that is not given the same consideration as other developmental problems in a variety of educational settings [8]. The most fundamental mathematical ideas are frequently difficult for students with dyscalculia to grasp, which has a big effect on their academic achievement and ability to learn life skills [9]. Despite the severity of the issue, there are currently no specialist programs in Latin America that methodically address this challenge, underscoring the necessity of developing educational policies and pedagogical practices that support early detection and successful treatment [10].

Reigosa-Crespo *et al.* [11] it is mentioned that it arises from the mental deficit of numerical representations or derivatives. In an investigation in [12] it was demonstrated through the use of "AR VR Molecules editor", an application based on AR, an increase in academic performance, as well as in the retention of information, it was shown that the application meets the needs of these children, as well as in their learning process. Being AR a technology that harbors many benefits in the educational environment in which children, mainly with special needs can develop their cognitive skills.

Compared to these studies, which demonstrate the general potential of AR in inclusive education, this study proposes a more innovative approach by applying this technology specifically to the treatment of dyscalculia, incorporating elements of gamification, accessibility, and inclusive design. Unlike other educational tools that are limited to the visual representation of mathematical operations, this platform integrates an adaptive interaction system that adjusts the difficulty of activities based on the child's performance, encouraging immediate feedback and positive reinforcement. Furthermore, it introduces visual components designed in collaboration with education specialists, ensuring the pedagogical appropriateness of the content to the cognitive characteristics of dyscalculia. The proposal also stands out for its structured validation model, which includes evaluation by experts in educational technology and inclusive pedagogy, surpassing the descriptive approach of previous studies and providing evidence of real-world applicability.

In the mentioned context, the objective is to design an educational platform that uses AR to improve the learning process in children with dyscalculia. This platform will have adaptive and personalized educational contents that contribute to their cognitive development. The study also seeks to establish a validation model that allows for the evaluation of the prototype's usability, functionality, and pedagogical suitability, ensuring its relevance in real-world teaching environments. In this work we will address various aspects related to the research, in section 2 we will explain about the literature review, in section 3 about the methodology, in section 4 we will explain the results of the research, as well as the discussions, ending with section 5 where the conclusions will be presented.

2. LITERATURE REVIEW

This section will address the literature review, corresponding to the analysis of other research within the field of special needs, AR and dyscalculia. Studies that examine how this technology can improve accessibility and quality of life for children with special needs, especially in educational contexts, will be explored. In view of the rise of new technologies, especially AR as something innovative and with potential for use in learning [13], sought to determine the effectiveness of this technology in educational environments, precisely where students have difficulty learning mathematics (Dyscalculia). For the development of this research, an experimental approach was used, with a sample of fourth grade students, divided into 2 groups, one group using AR and the other using traditional methods. As a result, the use of AR in the learning process had a moderate effect, enriching the cognitive skills of the students. Similarly, the arithmetic average of the students before the test was 1.749, while after the test it was 2.375, indicating that this technology is accepted and effective towards the teaching and learning process. Comparatively, this study demonstrates the positive impact of AR on the development of basic mathematical skills. However, its approach does not delve into the specific pedagogical adaptations needed to serve students with dyscalculia. This demonstrates a general focus on improving learning, rather than addressing a specific cognitive difficulty.

In recent years, technologies such as VR and AR have become more relevant in various fields, education being one of them. In this sense, Stasolla *et al.* [14] this technology is used to evaluate learning through a test in 15 students with dyscalculia in an elementary school. On the other hand, there was a formative and a summative evaluation, the first corresponding to 5 experts based on a functional prototype with AR, where 99.23% agreed that there were no problems with the prototype interface; 80% regarding effectiveness and 72% strongly agreed regarding interactivity. The second evaluation was directed to the students based on

the learning construction capacity in usability of the prototype, achieving a 98.8% success rate. Based on the study, it was concluded that those suffering from dyscalculia need interactive elements to improve and enjoy more the learning process, being the AR technology able to help and improve the cognitive process. In addition, it is highlighted that its use has a positive and enriching impact during learning. Comparing these results reveals progress toward a more comprehensive validation of the prototype, incorporating the opinions of experts and end users. However, both studies focus on perception and acceptance of AR use, without directly assessing academic performance or improvements in numerical understanding, which limits the generalizability of their findings to specialized therapeutic or educational contexts.

There are several learning difficulties that affect the cognitive development and learning process of children, one of these being dyscalculia, which is closely related to learning in mathematics. In that sense, in [15] using emerging technologies such as AR, a prototype application based on AR was designed, focusing on gamification, to enhance the assimilation of arithmetic concepts. This study had a design approach where the prototype of the application was made and an experimental approach where 18 boys and 22 girls between the ages of 7 and 9 years participated. As a result, it was obtained that when using the application, the children presented higher performance (9.0) with respect to the traditional form (7.85). Consequently, it was determined that both the use of gamification and AR demonstrate significant effects with respect to levels of comprehension of basic and sequential mathematical operations, as well as increasing the interest and motivation of children. Compared to previous studies, gamification is incorporated as a motivational strategy, providing a playful component that complements AR. However, the analysis is limited to measuring overall performance, without linking the results to the specific cognitive characteristics of children with dyscalculia.

Learning difficulties greatly affect children during their school years, generating stress and difficulty in understanding concepts in class. Lazo-Amado *et al.* [16] we sought to design a mobile application using AR to support children's learning difficulties through interactive educational games. For its development, the design thinking methodology based on 5 phases, emphasize, define, ideate, prototype, and test, was used. Marvel app was used for the design of the prototype and Tinkercad for the modeling of the elements in 3D and Augment class. As a result, the prototype was approved by experts, as well as by parents regarding the acceptance of the prototype for their children. Concluding that the prototype based on AR is of great help and improves the understanding of the subjects in the classrooms. This study shares the use of user-centered methodologies, although its scope is broader, encompassing diverse learning difficulties. In contrast, the present work focuses on a specific problem and how AR can adapt to its cognitive specificities.

Similarly, the impact of AR in education has gained more strength, in [12] focus both on those students with special needs and those without this condition, mainly in the subject of chemistry and its effect on academic performance. The aim of the study was to explore the educational possibilities offered by the integration of this technology, as well as its effect on students' academic performance. A quantitative approach and a pre-experimental design were used, with the application "AR VR Molecules Editor" during classes, which is an application designed to visualize and manipulate molecular structures in 3D using AR and VR, the results obtained showed a significant increase in academic performance and the ability to retain information. Thus, it was demonstrated that the application of technologies such as AR promotes performance in increasing cognitive development at the educational level and for those with special needs. Although AR's versatility in different areas of knowledge is demonstrated, its main contribution lies in the field of science, without addressing the numerical area or the cognitive processes involved in mathematical learning.

The theme numerical skills, related to neural processes, addresses the origin of dyscalculia explaining that this condition arises due to a deficit in mental numerical representations or derived processes. Reigosa-Crespo *et al.* [11] they seek to establish whether variations in numerical processing abilities were related to changes in local cortical structure. It is mentioned that numerical neurocognitive abilities are key in learning mathematics, and being directly related to the learning process are a common cause of difficulty in acquiring these skills. Collaboration between teachers and neuroscientists can promote and enhance interventions that contribute to the development of mathematical skills taking advantage of the classroom and educational technology, thus promoting equitable and quality education. In contrast, this study complements the aforementioned by providing a prototype approach related to dyscalculia applications, which is relevant given the need for technological solutions required in this field.

Dyscalculia, a disorder characterized by difficulty in learning mathematics, especially in children, is the focus of [17] where the aim is to develop a plan for an innovative prototype with AR aimed at elementary school students. The design thinking methodology was used for the development of the research in order to better understand the problem and propose solutions. As a result, a great acceptance was obtained from parents, who expressed that the prototypes are a valuable contribution to their children's learning. The contents of the prototypes included educational dynamics that helped the children develop their skills. In addition, the prototypes were validated by experts, reaching 86% acceptance. In the development of this research, we sought to improve the learning process of children with dyscalculia at the primary level, so the development of the prototypes with AR focused on the ease of understanding through dynamic games. This work addresses the

objective of the present study by linking AR with dyscalculia care. However, it is limited to prototype acceptance, without measuring the actual impact on users' mathematical understanding or cognitive improvements.

Similarly in [18], given that dyscalculia is a learning difficulty that affects between 3% to 8% of the population, we sought to develop “Chocolator” a playful application designed to help teachers support mathematical learning more attractively for students. As a result, a calculator was obtained where the solutions were represented by chocolate fractions referring to the number of the answer, through addition, subtraction and division operations. Consequently, it was determined that in this way children can more easily understand abstract mathematical concepts, as well as being a support to strengthen traditional teaching methods by using new technologies. Compared to other studies, [18] presents an innovative proposal in the recreational field, although its scope is restricted to the visual representation of basic operations, without considering feedback processes or cognitive adaptability, aspects that this work seeks to incorporate.

Overall, the reviewed works demonstrate a growing interest in the application of emerging technologies, especially AR, as a support tool in special education due to its potential to promote cognitive development and learning. However, most studies focus on the usability or acceptance of prototypes, neglecting the specific cognitive analysis required by dyscalculia. Despite the progress made, research that applies AR specifically to this disorder, integrating personalization strategies, immediate feedback, and experimental validations on numerical learning, is still scarce. In this context, this study seeks to provide a more comprehensive approach that combines AR with accessibility principles, inclusive design, and expert evaluation, aimed at improving educational understanding in children with dyscalculia.

3. METHOD

This section explains the methodology used in this work, the research was conducted under the Scrum methodology with which the design of the educational platform based on AR to improve the education of children with dyscalculia was carried out. The design of this platform is developed in “UNITY”, which allows 3D modeling and programming in C# language [19]. Similarly, a software development kit for AR called Vuforia [20], [21] was used, which acts as an intermediary between reality and the virtual environment to display images of the real world on the screen of the device as a projection.

3.1. Scrum

Regarding the methodology, Scrum is a framework based on an agile approach, which helps the development of projects of all kinds in a fast and simple way. Likewise, it consists of a series of different stages or steps to follow. In addition, Scrum is based on five fundamental values: commitment, focus, openness, respect, and courage [22], [23], which are essential for collaboration and project progress. This agile methodology presents three important pillars, transparency, inspection, and adaptation [24], each of them with a fundamental role that guarantees the fulfillment of the objectives in a project.

The product backlog is one of the most important components within this agile framework [25], in it are the functionalities or software modules, epics and user stories (HU), the latter consists of 3 parts, the role, the functionality and the business need of what is sought to develop, to determine these user stories is performed several meetings with customers or also known as Stakeholder. To ensure that the development of the platform meets the specific requirements and needs, a series of user stories have been defined. Table 1 presents these stories, which detail the key functionalities and features of the prototype, allowing a clear view of the expectations for each phase of development.

Table 1. User story

User story	
H1	As a teacher, I want to visualize a login interface in the prototype to access the application.
H2	As a teacher, I want to visualize an admin interface in the prototype to manage my profile and view users.
H3	As a teacher, I want to visualize a section in the prototype to download the source code.
H4	As a teacher, I want to visualize a role interface in the prototype to access each content.
H5	As a student, I want to be able to select the type of math exercise in AR on the interface to solve it.
H6	As a student, I want to be able to register in order to access the content.
H7	As a student, I want to be able to use the camera to access additional content in AR.

3.2. Fibonacci estimation

The Fibonacci series is used to estimate the product realization time, using numbers (0, 1, 2, 3, 5, 8, and 13) that represent the days [26]. These are assigned according to the complexity of the tasks since it is the

number of days it takes to perform them. At the end, all the assigned points are added up resulting in the number of days it will take to realize the software module or product.

After establishing the user stories, we proceeded with the development of the Fibonacci estimation as shown in Table 2. This phase facilitates the evaluation of the effort required for each task, assigning numerical values based on the complexity and estimated time. Once the user stories were defined and their complexities estimated, the sprints were planned (see Table 3). This stage made it possible to organize the work in short development cycles.

Table 2. Planning poker

No	User story	Team Scrum			Points
1	As a teacher, I want to visualize a login interface in the prototype to access the application.	3	3	3	3
2	As a teacher, I want to visualize an admin interface in the prototype to manage my profile and view users.	3	5	5	5
3	As a teacher, I want to visualize a section in the prototype to download the source code.	2	2	2	2
4	As a teacher, I want to visualize role interface in the prototype to access each content.	5	5	5	5
5	As a student, I want to be able to select the type of math exercise in AR on the interface to solve it.	8	8	8	8
6	As a student, I want to be able to register in order to access the content.	3	3	3	3
7	As a student, I want to be able to use the camera to access additional content in AR.	2	3	3	3

Table 3. Sprint planning

No	User story	Days	Sprint
1	As a teacher, I want to visualize a login interface in the prototype to access the application.	3	1
2	As a teacher, I want to visualize a section in the prototype to download the source code.	2	1
3	As a student, I want to be able to register in order to access the content.	2	1
4	As a teacher, I want to visualize an admin interface in the prototype to manage my profile and view users.	5	2
5	As a teacher, I want to visualize a roles interface in the prototype to access each content.	5	2
6	As a student, I want to be able to select the type of math exercise in AR on the interface to solve it.	8	3
7	As a student, I want to be able to use the camera to access additional content in AR.	3	3

3.3. Sprints

This is one of the most important activities within the Scrum methodology, in which the tasks or user stories are separated into groups, or also called sprint, which should last between 2 to 4 weeks, i.e., the time in days of realization of the user stories should not exceed 4 weeks [25], [27]. Each sprint must be completed in the estimated time, including improvements or modifications if necessary. Likewise, the whole team meets to move on to the sprint planning phase. For the development of the sprint, the user stories of the product backlog were taken into account, thus defining 3 sprint, in which each one is defined by its story number, the user story itself, the estimated time, the developer, the user or customer, the description and the acceptance criteria.

The first sprint focused on the creation of a basic prototype of the platform, which included the main interfaces such as the welcome screen (see Table 4). The user story sprint related to the download of the source code is also presented, highlighting how the interface allows the user to perform this process safely. Finally, with the user story sprint related to the user registration process. In the second sprint, we worked on the implementation of the administrator interface, to manage the profile and visualize the registered students or users (see Table 5). In addition, we developed the role selection functionality, differentiating between administrators and students.

Table 4. User story-sprint 1

No	User story	Estimated	Developer	User	Description	Criteria of acceptance
1	As a teacher, I want to visualize a login interface in the prototype to access the application.	3	Jhair	Teacher	In this interface, the user will be able to log in to the application to access content according to their roles.	The interface must allow login using a username and password to access the application.
2	As a teacher, I want to visualize a section in the prototype to download the source code.	2	Jhair	Teacher	In this section, the developer or teacher will be able to download the source code of the application in order to make improvements.	There must be a button or link within the application that allows the registered teacher or developer to download the source code.
3	As a student, I want to be able to register in order to access the content.	2	Jhair	Student	In this section, the student will be able to register their account to access educational content.	A user registration interface should be displayed, which must include fields such as: name, age, username, email, password, and role.

Table 5. User story-sprint 2

No	User story	Estimated	Developer	User	Description	Criteria of acceptance
4	As a teacher, I want to visualize an admin interface in the prototype to manage my profile and view users.	5	Enrique	Teacher	In this section, the teacher will be able to view content such as users and their profiles.	There should be a button to view the list of registered users, as well as another button to view their own profile.
5	As a teacher, I want to visualize a roles interface in the prototype to access each content.	5	Enrique	Teacher	In this section, two buttons will be displayed that allow the user to access their respective interface, either as a developer or as a teacher (administrator).	There should be two buttons that redirect the user to their respective interfaces.

The third sprint focused on working on the functionality that will allow students to select the mathematical operation they wish to solve within the platform (see Table 6). Additionally, the integration of the AR functionality through the camera was designed, which will allow students to interact in an immersive way with additional educational content. For the development of the prototypes, Figma [28] was used, which is a tool that allows the design of prototypes for different devices, as well as Unity as a development environment. Based on this, we started with the design of the prototypes based on AR.

Table 6. User story-sprint 3

No	User story	Estimated	Developer	User	Description	Criteria of acceptance
6	As a student, I want to be able to select the type of math exercise in AR on the interface to solve it.	8	Sebastian	Student	In this section, the student will be able to select the button for the mathematical operation that will take them to the respective levels to solve it in AR.	There should be buttons that reference the respective mathematical operations, and each of them should direct the student to the corresponding topic.
7	As a student, I want to be able to use the camera to access additional content in AR.	3	Sebastian	Student	In this section, the camera will display content in AR when recognizing a specific object or image.	The camera should be able to be used additionally by focusing on a specific object or code to access more content in AR.

3.4. Pedagogical model of the application

The innovation lies not only in the use of AR as a visual resource, but also in the integration of an adaptive pedagogical model that responds to the cognitive needs of children with dyscalculia. The pedagogical approach is based on principles of meaningful learning and feedback, allowing students to progress progressively based on their performance.

From a pedagogical perspective, the activities are structured into three levels of complexity: i) number recognition and visual correspondence, where the student identifies quantities associated with 3D objects; ii) guided basic operations, in which the system reinforces the concepts of addition and subtraction through visual and auditory support; and iii) free application challenges, in which the child must solve practical problems with AR visual stimuli that change according to their progress.

Regarding the interaction design, AR is used in an immersive and manipulative manner. The three-dimensional elements appear superimposed on the real environment, allowing the student to directly interact with the numerical objects through device movements. This approach seeks to reinforce symbolic-numerical associations and stimulate visuospatial memory, aspects particularly compromised in dyscalculia.

Furthermore, the platform incorporates a personalization engine that adjusts both the difficulty of the content and the sequence of activities according to each student's individual profile and progress. During the registration process, the system creates an initial profile that considers the student's educational level in the first interactions. Based on this data, the student is classified into one of three levels of proficiency (basic, intermediate, or advanced), adapting the response time and level of attendance during the activities.

Progress is continuously recorded through an internal tracking system that stores the results of each session: correct answers, errors, time spent, and frequency of interaction. This information is used to dynamically adjust upcoming activities, reinforcing the areas where the student experiences the greatest difficulty and reducing complexity when the error level exceeds a predefined threshold. Finally, the personalization engine generates a performance history that can be consulted by the teacher or specialist, allowing progress to be monitored and external teaching strategies to be adapted. In this way, the application

not only reacts to the student's performance in real time, but also learns from their behavior, thereby ensuring a truly inclusive and adaptive educational experience.

Furthermore, the application design was validated by experts in education and educational technologies, who reviewed the content, the sequence of activities, and the appropriateness of the visual and auditory stimuli to the characteristics of children with dyscalculia. This validation guaranteed that the proposal not only fulfills a technological function, but also a didactic one, aligned with the real needs of users.

3.5. Integration of the cognitive model into the design

The platform's design is based on neurocognitive frameworks linked to numerical processing and the learning mechanisms involved in developmental dyscalculia. The initial activities, focused on identifying objects and quantities, link concrete magnitudes with three-dimensional visual representations. In later stages, symbolic activities, such as number recognition, guided operations, and problem-solving, promote the integration of visual perception and numerical representation.

Furthermore, the applied cognitive model considers the principles of the dual route theory of numerical processing, which distinguishes a verbal pathway (for learning memorized arithmetic facts) and a visuospatial pathway (for reasoning and estimating quantities). The application's interface stimulates both pathways: auditory instructions and verbal feedback; and manipulable spatial representations in AR that allow quantities to be visualized and compared in a tangible way. From an attentional and motivational perspective, positive reinforcement mechanisms are incorporated, which activate reward circuits associated with meaningful learning, maintaining motivation and reducing frustration in children with dyscalculia.

Overall, the integration of the neurocognitive model allows the application to not only be limited to practicing mathematical exercises, but also act as a tool to stimulate executive functions, such as sustained attention, working memory, and cognitive flexibility, which are essential for the development of numerical skills. In this way, the application design is linked to neuroeducational evidence, ensuring that the AR interactive dynamics respond to the cognitive processes in dyscalculia.

3.6. Technical details and application compatibility

The application was developed in the Unity 3D environment (version 2022.3 LTS) due to its cross-platform compatibility and the ease with which it integrates interactive three-dimensional content. For the implementation of AR, the Vuforia Engine SDK (version 10.25.4) was used, selected for its stability, real-time image recognition capabilities, and direct integration with the Unity engine.

The app was programmed in C#, using interface control and rendering libraries optimized for mobile devices. The three-dimensional models were designed in Blender and Fusion360 and subsequently integrated into unity with compressed textures. Regarding compatibility, the prototype was tested on android devices, ensuring a personalized functional experience for users.

Regarding latency and performance management, rendering optimization and parallel processing techniques were applied in Unity, reducing the delay between camera capture and virtual projection. Texture caches and an object preloading system were used to maintain stable frames per second (FPS) between 30 and 60 on mid-range devices. Additionally, an automatic light calibration algorithm was incorporated to adjust the contrast of AR elements to the user's physical environment, reducing marker recognition errors in variable lighting conditions.

To manage network latency and communication between modules, a local-host data exchange channel with asynchronous synchronization was implemented, avoiding overloading the system's response. In this way, the prototype guarantees fluid and stable interaction, an essential condition for maintaining immersion and immediate response in AR educational activities. The platform's modular design also allows for future extensions to other operating systems, such as iOS or WebGL, while maintaining the basic structure of the unity engine and managing dependencies through external packages such as asset management.

4. RESULTS AND DISCUSSION

4.1. About the prototypes

In this section, we present AR-based educational prototypes designed to help children with dyscalculia between the ages of 8 and 10. The prototypes include several key interfaces that facilitate user interaction and navigation through the educational content. In terms of results, Figure 1 shows the welcome screen, which warmly welcomes users with a brief description of the application. This interface is designed to be intuitive and appealing to children.



Figure 1. Application welcome

Figure 2 presents the login and registration screens, crucial to allow secure and easy access to the platform. Figure 2(a) the prototype allows the user to log in to the application with their username and password. Likewise, Figure 2(b) shows the interface where the user can register an account with their first name, last name, age, username, email and password, and then log into the prototype with the credentials created.



Figure 2. Interfaces for; (a) login and (b) user registration

An important feature of the platform is the ability to select different roles within the application. Figure 3 shows the role selection screen, where users can choose from several options according to their role in the platform. The roles within the prototype will allow redirecting each one with their respective interface.

The next part shows the interface intended for the student, where he can choose the mathematical operation, he wishes to develop, as well as its level of difficulty. This interface allows the student to select the type of operation (addition, subtraction, multiplication, and division) and adjust the difficulty according to his skills, as well as to see the corresponding content. Figure 4 shows the student interface, in which the student can select the mathematical operation to be performed and the difficulty level. Figure 4(a) shows the operation selection interface where the student will be able to select the operation, he wishes to solve, and then proceed to select the difficulty level according to his needs. Similarly, Figure 4(b) shows the levels of difficulty that the student can select to solve the 3D content.

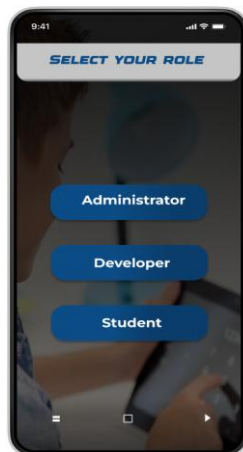


Figure 3. User roles

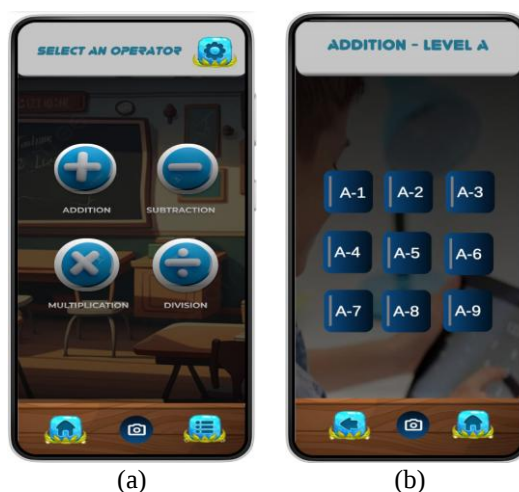


Figure 4. Interfaces of; (a) operator selection and (b) mathematical content

Once the student has selected a mathematical operation and a level of difficulty, an interface is presented where he must mark the correct alternative. This functionality is crucial to evaluate the student's progress and allow him to advance to higher levels. Figure 5 shows a 3D mathematical problem that the child can solve, as well as the interface that shows whether the answer is correct. Figure 5(a) shows how the mathematical content is manifested in 3D within the environment when using the cell phone camera, likewise the student has 3 options to select his answer that are later validated in the prototype. Figure 5(b) shows the validation of the answer, if it is correct, a congratulatory interface is shown and if not, an interface stating that it was not the answer and that he can try again.

Figure 6 shows the subtraction section with the activity using AR and the existing levels for the user to solve. Figure 6(a) shows a subtraction activity in which the correct option must be selected to continue to the next mathematical operation. Figure 6(b) shows the correctly completed levels with the assignment of 3 stars.

On the other hand, if a user wishes to view his progress, he must go to the respective interface. Figure 7(a) shows the user progress interface for each operation and difficulty. Figure 7(b) shows the interface for interacting directly with the AR through the camera.

4.2. Prototype interview and validation

Figure 8 shows the prototype category and its 5 subcategories. An interview was conducted with 4 users on functionality, adaptability, usability, interface design and user experience; where the most cited was interface design and usability, highlighting the importance for a prototype design of ease of use and user-friendly interface. In addition, the greatest number of code relationships was functionality and adaptability

through the association between them and others. They also emphasized that interaction should be easy and this should be complemented with colors, buttons, and others.



Figure 5. Interfaces of; (a) mathematical operation and (b) result

Figure 6. Interfaces of; (a) subtraction operation and (b) completed levels

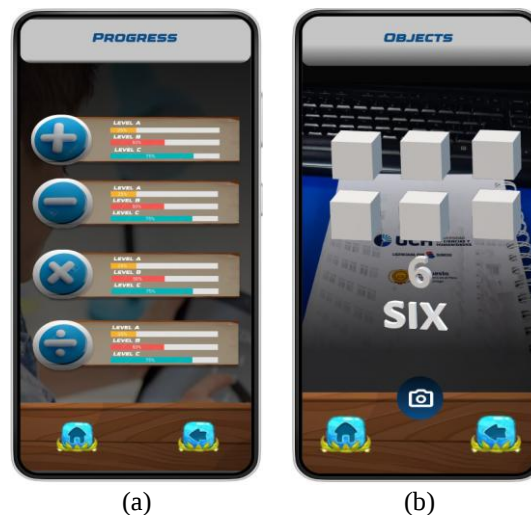


Figure 7. Interface of; (a) progress and (b) use of the camera to visualize AR

Likewise, children with dyscalculia and teachers specializing in inclusive education participated in usability tests with the four users. The purpose of this test was to obtain direct feedback on the ease of use, the clarity of the instructions, and the level of motivation generated by the AR environment.

During the sessions, the children emphasized that "the shapes helped them better understand numbers" and that "the activities seemed like games", indicating a positive perception of playful learning and interaction with virtual objects. The teachers also highlighted the system's ease of navigation and its value as a complementary pedagogical support, noting that "the interface allows the pace of work to be adapted to each child" and that "the use of colors facilitates sustained attention". Overall, participants expressed a high level of acceptance of the prototype, particularly valuing its interactivity, accessibility, and ability to maintain the child's concentration.

The validation of the prototypes was carried out with the participation of six experts. The purpose of this validation was to evaluate various aspects of the prototype, using specific criteria as shown in Table 7. On the other hand, Table 8 shows the level of acceptance by the experts considering the criteria mentioned in the previous table.

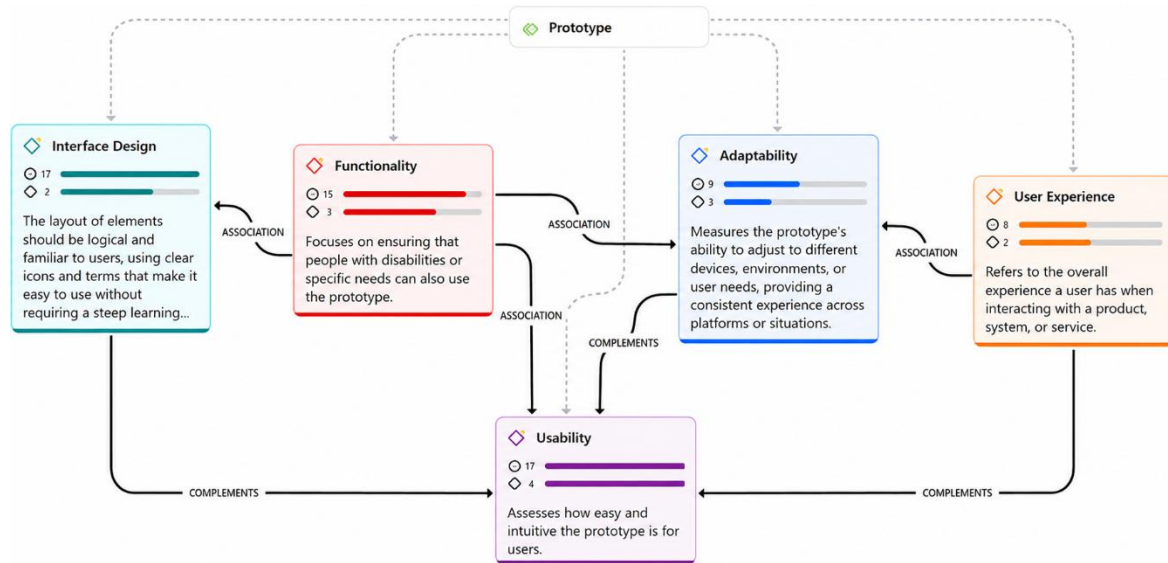


Figure 8. User interviews

Table 7. Prototype validation criteria

Item	Criteria
1	Usability: does the prototype design allow users to easily understand how to interact with the platform?
2	Interface design: is the visual design clear and helpful for understanding the information?
3	Functionality: are interactive features (such as 3D elements) effective for learning?
4	Adaptability: does the design allow adjustments for different levels of difficulty and user needs?
5	User experience: is the design appealing and does it hold the user's interest during use?

Table 8. Expert validation

Item	Criteria	E1 (%)	E2 (%)	E3 (%)	E4 (%)	E5 (%)	E6 (%)	Average (%)
1	Usability	80	100	100	100	80	80	90
2	Interface design	80	80	100	80	80	80	83
3	Functionality	60	80	80	100	40	100	77
4	Adaptability	80	80	80	100	80	80	83
5	User experience	60	80	100	60	60	80	73

The results showed that the prototype has a high level of acceptance in terms of usability 90%, design 83%, functionality 77%, adaptability 83%, and user experience 73%. Overall, the prototype was accepted and validated by the experts with an average of 81.2%, indicating that it is suitable to support children with dyscalculia in their learning process.

While the validation conducted allowed for the evaluation of the prototype's usability, functionality, and pedagogical relevance, clinical validation or validation in real school settings with children has not yet been carried out. This limitation is due to ethical and logistical considerations related to institutional authorization and the professional support required to work with children in situations of educational vulnerability. However, future considerations are proposed to evaluate the cognitive effectiveness of the system in real learning contexts, through controlled pilot tests and clinical observations of numerical performance and academic motivation.

Furthermore, performance metrics derived from user testing sessions were analyzed. These metrics were obtained from application logs and direct observation during activities to estimate the impact of the prototype on improving learning and attention. On average, children completed 92% of the tasks proposed within the AR environment, showing a 35% reduction in errors between the first and last activities. In addition, the average time spent solving each operation progressively decreased, indicating an improvement in processing speed and numerical comprehension. Regarding attention span, students were found to maintain active interaction for periods between 10 and 13 minutes per session, a value higher than the average observed in traditional activities (7 minutes). Teachers and observers reported that the 3D elements, immediate feedback, and the use of colors significantly increased motivation and sustained concentration.

In comparison with other research, as in [10], it was shown that AR had a positive impact on the learning of children with dyscalculia, increasing their academic performance. Similarly, in [18] where a

prototype with AR was developed for children with dyscalculia using the design thinking methodology, it had an acceptance rate of 86%. In contrast with our research that achieved an acceptance of 81.2% following the Scrum methodology. Demonstrating that the use of AR is promising to help these children. On the other hand, in [6], although they do not make use of AR, they present its application with a focus on helping children with dyscalculia, demonstrating that new technologies have the potential to improve the learning process. Compared to our research, the incorporation of AR offers a new, more interactive learning experience that benefits these children. Similarly, in [17] where the prototype of the AR application achieved an acceptance of 85.4% focused on learning difficulties, including dyscalculia.

From an electrical and electronic engineering perspective, the app's technical performance was analyzed, considering the sensor interface, hardware responsiveness, and the integration of AR components. The system uses the mobile device's camera as a motion and image capture sensor, utilizing the Vuforia recognition engine for marker tracking and accurate real-time 3D object overlay. Testing showed a recognition rate of over 95% in well-lit environments, maintaining an average latency of less than 300 milliseconds between visual recognition and augmented projection.

The app also includes a proximity and orientation sensor interface provided by the device's gyroscope, allowing the 3D display to be adjusted based on the user's inclination or distance. This integrated processing contributes to a more natural and stable immersive experience. Regarding the AR hardware architecture, the app was optimized to run on mid-range Android devices and higher, with support for an Adreno 600 GPU or higher and an autofocus camera. This demonstrates that the app combines processing stability, visual precision, and low power consumption, essential aspects to ensure its scalability in future real-life school settings.

Regarding IT integration and data management architecture, the app incorporates an online progress tracking system, which allows the storage and synchronization of each user's learning results. This feature ensures the continuity of the educational process, even if the student uses different devices or changes school environments. The stored data includes the history of completed activities, interaction time, levels achieved, and recurring errors, facilitating performance analysis. Furthermore, the system incorporates an adaptive learning algorithm that analyzes student progress in real time. This algorithm adjusts the level of difficulty, practice intervals, and the presentation of visual stimuli based on previous performance and success rate. Thus, the platform combines the benefits of online storage with intelligent learning personalization, creating a digital system focused on the continuous improvement of the cognitive performance of children with dyscalculia.

Despite the results obtained, technical and contextual limitations were identified that must be considered for future implementations. First, the dependence on a mobile device represents a significant challenge, as system performance varies depending on processor capacity, camera resolution, and connection stability. Furthermore, technological accessibility in low-resource institutions constitutes a potential barrier. Not all schools have compatible devices or sufficient infrastructure to continuously implement AR-based tools. Another relevant aspect identified is the cognitive load that can be generated in some children during the first sessions. While 3D interaction favors attention and motivation, the excessive visual stimuli of tasks could hinder the assimilation of content for users with less attention spans. Taken together, these observations identify areas for improvement and reinforce the importance of continuing to develop more accessible, lightweight, and adaptive versions of the prototype that maintain their positive impact in contexts of technological and cognitive diversity.

Regarding implementation viability and scalability, the app shows high potential for integration into special education programs at both the institutional and national levels. Its modular architecture allows for gradual adaptation to different school contexts, from urban institutions with advanced technological infrastructure to rural schools with limited connectivity. For the latter, the development of an offline version with delayed synchronization is planned, which would allow the use of educational resources without requiring a constant internet connection. At the operational level, the app could be integrated into the pedagogical support curriculum of the Peruvian Ministry of Education's national inclusive education programs, through inter-institutional partnerships with universities and technological innovation centers. Furthermore, its scalable design allows for the incorporation of specific modules for other learning difficulties, such as dyslexia or attention disorders, which would expand its reach within the educational ecosystem.

In terms of sustainability, the proposal contemplates the possibility of establishing a phased implementation model, beginning with pilot projects in inclusive schools and subsequently expanding to regional networks. This approach would ensure continuous evaluation of the pedagogical and technological impact, allowing for system optimization as its implementation becomes more established at different levels of the education system. In this way, the application represents a support tool for dyscalculia and a replicable model for AR-based educational innovation.

Finally, the system's potential integration into real-life learning and therapy contexts was analyzed, considering different application scenarios. In the school setting, the platform can be incorporated as a complementary resource within math or cognitive reinforcement sessions, using mobile devices or tablets in

small groups under the supervision of specialized teachers. In the therapeutic setting, the tool offers an interactive environment for cognitive stimulation, ideal for psych pedagogy or occupational therapy sessions focused on improving numerical and attention skills. Its use in this context favors personalized work pace and direct observation of progress, which provides useful evidence for specialists in case follow-up. These features make the platform a flexible tool, adaptable to hybrid teaching-learning models that combine in-person and virtual spaces, reinforcing student autonomy and motivation.

5. CONCLUSION

Based on the results obtained, it can be concluded that the prototype design focused on the use of AR is an effective tool accepted by 81.2% of experts. Following the Scrum methodology allowed us to make early adjustments to the prototype design to meet the objectives. The prototype, designed specifically to support the learning of children with dyscalculia and with an attractive gamification-based design, allows them to interact with 3D content dynamically and with multiple options, unlike traditional teaching methods. The use of this new technology promises to facilitate a better understanding of mathematical concepts that children often find difficult, providing a more engaging experience in their education. However, given that the AR-based educational platform has not yet been implemented in a real environment with children with dyscalculia, it is not possible to conclusively state, either in the summary or in the conclusions, that it is an effective tool for their support, as this requires validation in practical contexts. In this regard, future research suggests implementing the prototype in real environments, after an experimental phase, to better understand its impact in the educational field and to what extent it influences student performance.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Jhair Baltodano-Payahua		✓	✓			✓	✓		✓	✓				
Sebastian Ramos-Cosi	✓	✓	✓	✓		✓			✓			✓		
Alicia Alva-Mantari		✓				✓	✓			✓	✓		✓	
Gustavo Villar-Mayuntupa	✓			✓	✓	✓		✓		✓				
Enrique Lee Huamani		✓	✓		✓			✓	✓		✓			✓
Meyluz Paico-Campos	✓			✓		✓	✓			✓		✓		
Laberiano Andrade-Arenas	✓	✓	✓	✓	✓	✓			✓	✓			✓	

C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : **O**riginal Draft

E : **E**diting

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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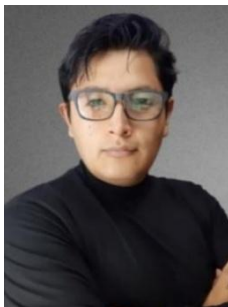
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BIOGRAPHIES OF AUTHORS



Jhair Baltodano-Payahua    is a student of Systems Engineering and Computer Science, Universidad de Ciencias y Humanidades. He has knowledge in web and mobile application development. He can be contacted at email: jbaltodanopayahua@gmail.com.



Sebastian Ramos-Cosi    received his B.Sc. degree in electronic engineering with a major in telecommunications at Universidad de Ciencias y Humanidades and Mg(c) technology educative, also graduated as a Professional Technician in Industrial Electronics. His research interests are in the area of agricultural technology, aerospace engineering, virtual reality and augmented reality. Currently, he works in the Image Processing Research Laboratory (INTI-Lab). He can be contacted at email: sramos@uch.edu.pe.



Alicia Alva-Mantari    has a Master's degree in biomedical informatics in global health from the Universidad Peruana Cayetano Heredia in collaboration with the University of Washington, a scholarship in the QUIPU program and a degree in mathematics from the Universidad Nacional de Ingeniería. In recent years, she has developed Telemedicine projects, coordinating and supervising interventions in the Teleradiology Systems for Tuberculosis and Melanoma, with provincial institutions in the coast and highlands. She is also responsible for the development of diagnostic software based on pattern recognition for various diseases such as tuberculosis, melanoma, bacterial vaginosis, intestinal parasitosis, plasmodium falciparum, among others. She has actively collaborated and has been responsible for the implementation of Telemedicine projects since 2008. She was for 10 years a member of the Bioinformatics and Molecular Biology laboratory of the Universidad Peruana Cayetano Heredia. For 7 years she has been a researcher at the University of Sciences and Humanities, with which she has won and directed research projects financed with national and international funds, among which are some oriented to support technology to combat COVID-19, metal contamination, among other issues of national interest. She can be contacted at email: aalva@uch.edu.pe.



Gustavo Villar-Mayuntupa    Graduate in Psychology, Master in University Teaching and Doctor in Educational Sciences. Academic director of the Universidad de Ciencias y Humanidades. Accredited by CONCYTEC as a RENACYT researcher. Professor in Scientific Research Methodology in Undergraduate and Reality and Trends of University Education in postgraduate. Lines of research focused on didactics and use of information technologies in university education. Guest professor of the master's degree in Education with a mention in Teaching and Higher Research at the Universidad Peruana Cayetano Heredia. He can be contacted at email: gvillar@uch.edu.pe.



Enrique Lee Huamani    is a systems and computer engineer from the University of Sciences and Humanities (UCH) and hold a Master's in Information Technology Management from the Newman Graduate School. He has extensive experience in artificial intelligence, machine learning, and big data, working as a senior programmer analyst in various programming languages, including Java, C#, C++, and PHP, utilizing the .NET framework. He has developed mobile applications and conducted research in supercomputing and high-performance cluster architectures. Currently, he is a professor and researcher at UCH, conducting studies at the Image Processing Research Laboratory (Inti-Lab). He has participated in projects such as LATITUD, a digital real estate management platform funded by ProInnovate, and have conducted workshops on artificial intelligence at the National University of Río Negro, Argentina. He can be contacted at email: ehuamaniu@uch.edu.pe.



Meyluz Paico-Campos    has a degree in Systems Engineering and Computer Science, and is a researcher at the Universidad de Ciencias y Humanidades. She proposes technological and innovative solutions to address various social problems in inclusive education. She has published in journals indexed in Scopus. She can be contacted at email: mpaico@uch.edu.pe.



Laberiano Andrade-Arenas    Doctor in Systems and Computer Engineering. Master in Systems Engineering. Graduated with a Master's Degree in University Teaching. Graduated with a Master's degree in accreditation and evaluation of educational quality. He is a systems engineer and scrum fundamentals certified, a research professor with publications in Scopus-indexed journals. He can be contacted at email: landrade@uch.edu.pe.